

ION INDUCED ELECTRIC FIELD TRANSIENTS ... THE SINGLE-EVENT GATE RUPTURE (SEGR)

By

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(Summary of research presentation)

Synopsis: Power MOSFET devices are susceptible to heavy-ion induced Single-Event Gate Rupture. Computer modeling show that intense electric field transients can trigger the SEGR phenomenon.

Summary: The age of space exploration may not have had its birth with the invention of the transistor. However, half a century after its introduction to the world, the transistor has made it possible for humans to explore the solar system.

The neural system of a spacecraft is its on board computer; hundreds of integrated circuits (IC) make up the computer. Each IC is made up of thousands or millions of interconnecting transistors on a single silicon wafer.

Power MOSFET Structure

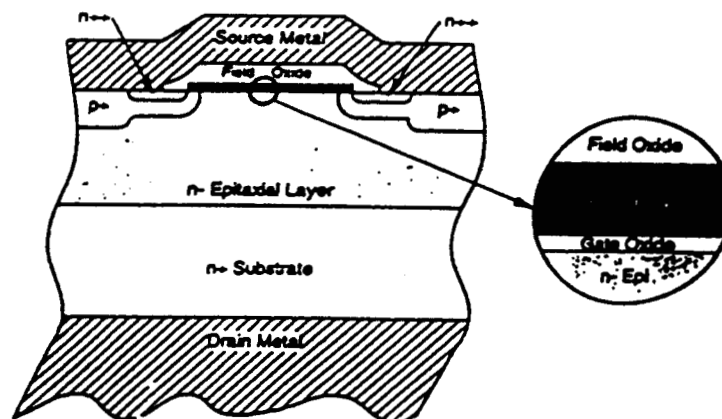


Figure 1. Generic Power MOSFET Structure

Figure 1 depicts a typical power MOSFET (metal oxide semiconductor field-effect transistor) structure. Power MOSFET are a special type of transistors. Transistors are a subset of complementary metal oxide semiconductor (CMOS) technology. The operational scheme for MOSFET are as follows. Two regions, the source and the drain, have a surplus of electrons and hence they are called n- (for "negative") type. The p- (positive) type region has an abundance of electron vacancies (called holes). Above the epitaxial layer, which is made of a silicon semiconductor material, is an insulating layer of silicon dioxide (SiO_2). The gate poly (or simply gate) sits on top of the insulating layer. When a positive voltage is applied to the metal gate and a negative voltage to the drain, an electric field is set up between the gate, which penetrates the SiO_2 layer and drain. The electric field attracts electrons toward the interface between the epitaxial layer and the substrate (field effect). The electrons over populate the substrate, which create a field inversion. This inversion allows the substrate to permit current to flow from drain to source [1-4].

Integrated circuits on board a travelling spacecraft will be exposed to the radiation environment of space. Ionizing particles of high energy (galactic cosmic rays and or solar flares) will randomly bombard the craft. A few of these particles may induce an intense transient electric field, which may render the transistor useless, the so call **single-event effect**. The single-event gate rupture phenomenon is a destructive single-event [4-6].

In order to try to understand the mechanism of SEGR a three prong attack was implemented. First, conduct an extensive literature search on the subject and any relating matters. Second, present a plausible model explaining the phenomenon. And third, test the model by performing experiments on virtual and actual power MOSFET devices. PISCES, a commercial software package, was used to simulate electric fields prior to and following the passage of an ion through a power MOSFET structure. Power MOSFET transistors were then irradiated to failure at heavy-ions accelerator (Brookhaven National Laboratory Van de Graaff).

Six Harris FRL130 power MOSFET devices were radiated with Iodine, whose linear energy transfer (LET) is 60 (MeV/cm²·mg) with a range of 33 μ m. The characteristics of the device are as follows. Insulating gate oxide thickness 46 ± 4 nm, epitaxial depth of 20 μ m with doping of 1×10^{16} ion per cubic centimeter, and a substrate doping of 3×10^{15} ions per cc at 7 μ m shallower. The FRL130 is rated for 100 volts between drain to source (V_{DS}). For a given radiation run either V_{GS} (gate to source voltage) or V_{DS} were stepped (while the other was maintained fixed) and irradiated with a fluence step of 10^5 ions per cm² or until SEGR. Between irradiations, the transistor was measured with V_{GS} = specification maximum and V_{DS} = 0 volts, as well as, with V_{DS} = spec. max. and V_{GS} = 0 v. If device was stilling operational the voltage was stepped up and irradiated once more. Flux was maintained about 10^4 ions per cm² per second producing roughly ten second runs. All electrical characterizations (measurements) were performed with an HP4142b connected to a computer via a general purpose instrument bus (GPIB).

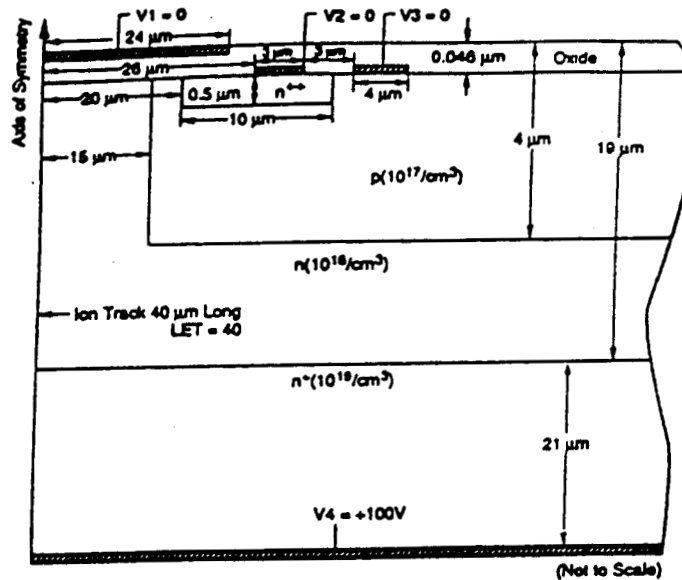


Figure 2. PISCES simulation geometry (cylindrical symmetry)

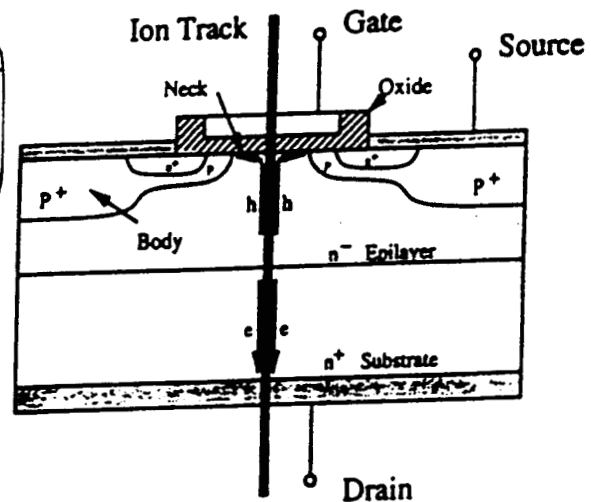


Figure 3. Power MOSFET structure, showing ion strike with holes moving upward and electrons downward under the influence of the positive drain voltage.

Figure 2 depicts the virtual power MOSFET used in the computer simulations. The physical dimensions and doping levels were selected to roughly correspond with the FRL130 device. Figure 3 shows a 40 μ m long ion track left behind by an ion with a LET of 40 MeV/cm²·gm with a gaussian radial distribution of 0.5 μ m. Electron-hole pairs (EHP) are created by the passage of the ion [5]. As in the case of figure 3, when a positive bias is applied on the drain, electrons are swept towards the drain and the slower holes migrate to the epitaxial substrate interface where they pileup[4,5]. Depending on the amount of energy imparted on to the electrons by the ion-induced electric field, ionized electrons will jump across the silicon band gap and on to the conduction band, a minimum of 3.6 eV is required for the creation of electron hole pair (EHP) [5]. If only enough energy to reach the lowest energy level on the conduction band is imparted on to the

electrons then any interaction and the electrons will recombine with holes and the excess energy will be liberated in the form of electromagnetic radiation [7].

Figure 4, shows the result of a PISCES simulation. Prior to the passage of the ion, the electric field at the oxide layer was about 1.7 MV/cm. 3.92 picosecond after the ion passed, the electric field strength was ~14 MV/cm, and increase of over 700%. A sustained electric field of this strength can strip electrons from the silicon dioxide molecules by a process known as avalanche. The avalanche path can then serves as a conduit for current flow from the gate through the insulating layer and substrate down to the drain, effectively shorting out the device [8-11]. Since figure 4 clearly indicates that the intense electric field lasts but for a tens of picoseconds, quantum mechanical tunneling is not expected to contribute to the SEGR failure. Avalanche is an impact ionization phenomenon where by energetic electrons, e.g., like electrons with high kinetic energy in the conduction band, collide with and ionize other electrons. Literally creating an avalanche of electrons.

Figures 5 and 6 shows preliminary results of a single experiment. The device failed during irradiation. Gate current, approximately -0.1 mA, is observed at the drain following irradiation, a clear indication of gate rupture. In figure 5, note that when the applied electric field (generated by V_{DS} of 37.5 volts) in combination with the passage of the ion resulted in the generation of an intense electric field transient, enough to trigger the gate to rupture. The sharp decrease in gate current seen at ~ 72 seconds, may be the first of three possible avalanches that lead ultimately to SEGR. Figure 6 shows the drain and source current during irradiation. Note the increase in drain and the decrease in source current during the irradiation, a clear indication that electrons are swept toward the drain and holes to the source (and Si/SiO₂ interface). Note, once again, that the drain current matches the amount of current "lost" at the gate.

The experimental results are in agreement with the postulated hypothesis that the Single-Event Gate Rupture (SEGR) phenomenon is trigger by the passage of an energetic heavy ion. It is the traversal of this heavy ion, through the power MOSFET, which induce an intense electric field transient at the silicon dioxide layer. Avalanche is postulated to be the mechanism by which the insulator breaks-down leading to the gate rupture.

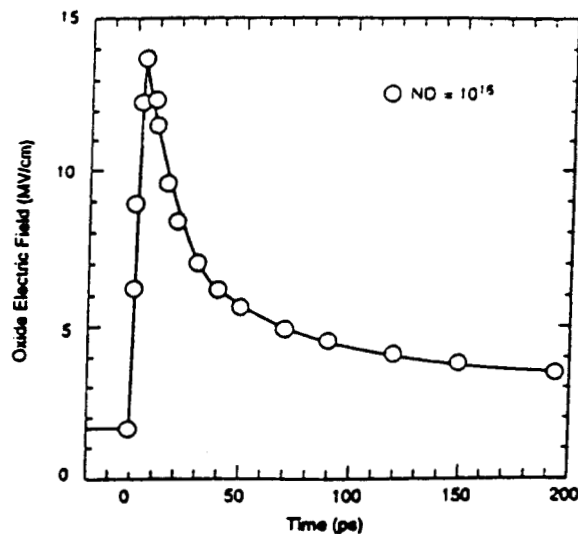


Figure 4. Simulation results for time dependence of the ion-induced electric field on the oxide following an LET=40, ion strike at $t = 0$.

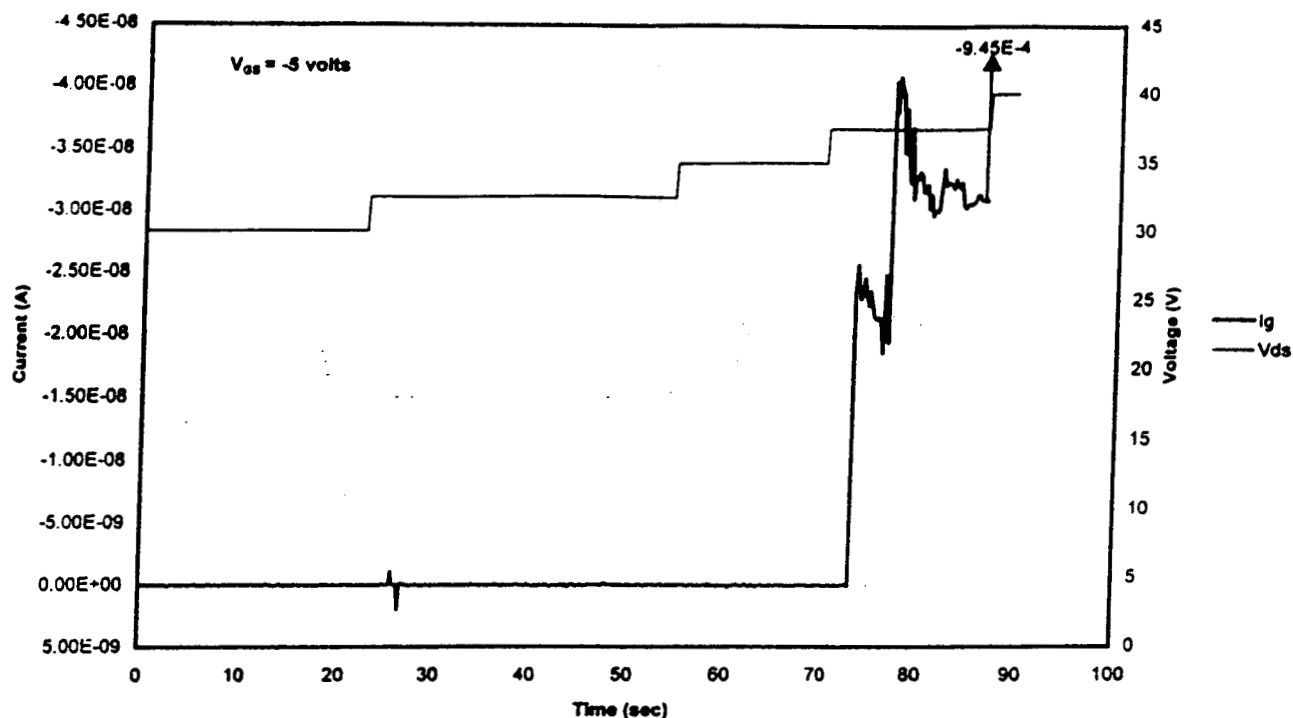


Figure 5. Actual data radiation experiment of a FRL130 transistor (Iodine ion).

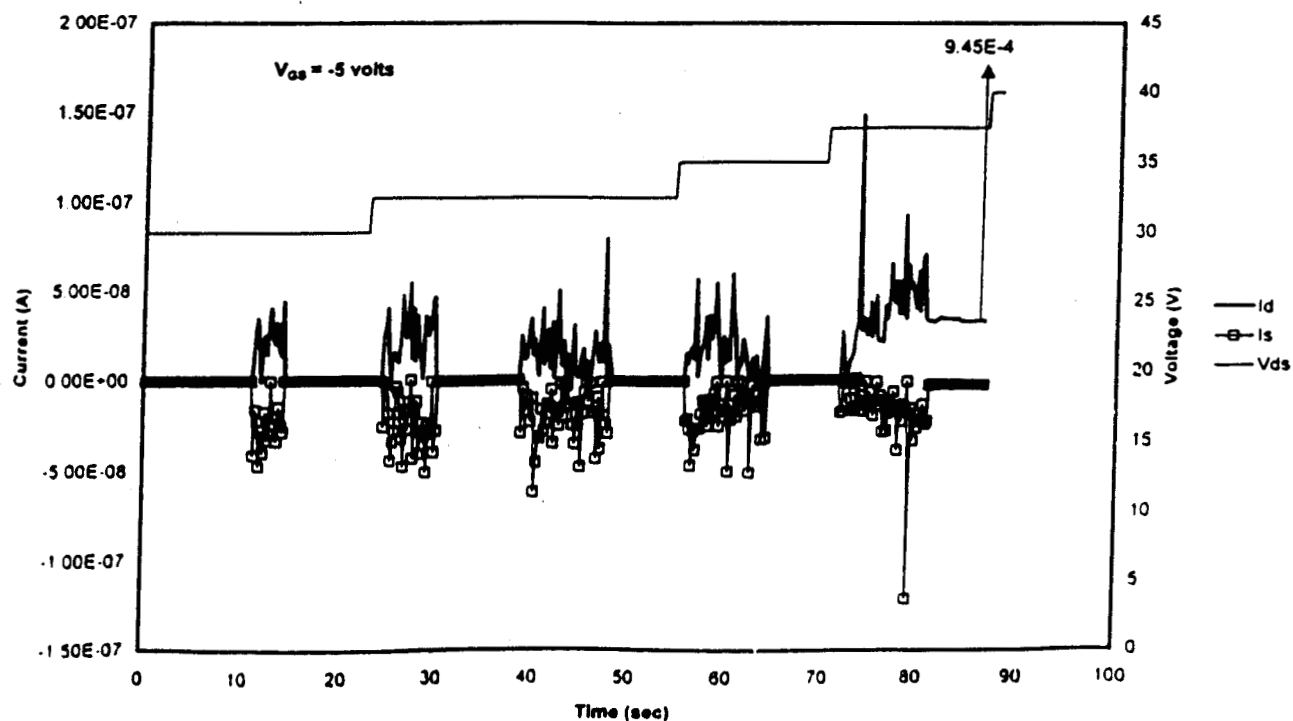


Figure 6 Actual data radiation experiment of a FRL130 transistor (Iodine ion).

Acknowledgement:

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Reference:

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Ion Induced Electric Field Transient ... The Single-Event Gate Rupture (SEGR)

**Presentation to the California State University, Chico
1998 Student Research Competition,
May 2nd, 1998
11:40 a.m.**

Luis Enrique Selva Rebollo

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Introduction

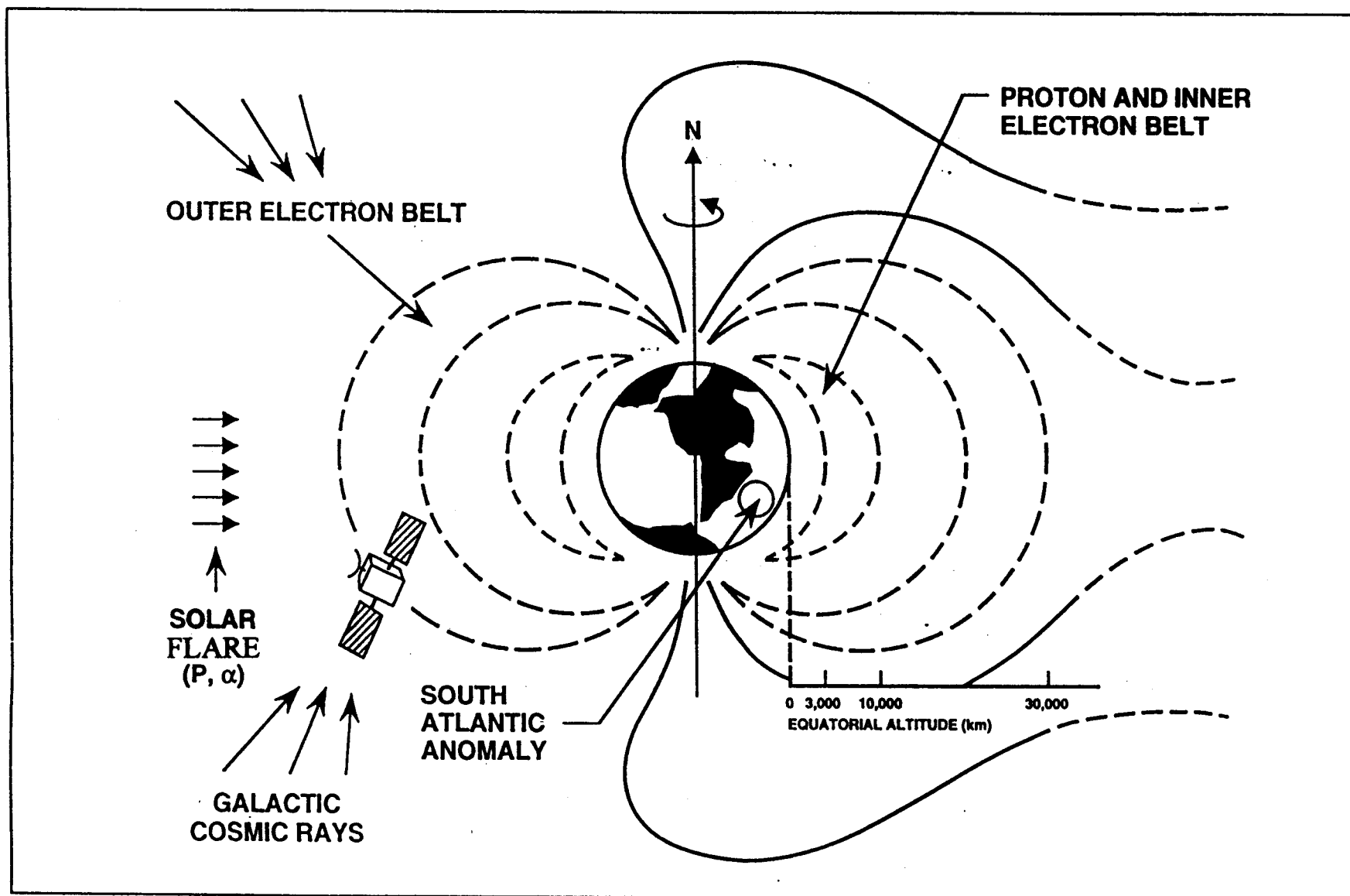
Controlling electron flow:

- (1906) Lee De Forest
- Shockley, Bardeen and Brattain (transistor)

Transistor:

- Introduced Tuesday 12/23/47
- Composite; *transfer* of electrical signal across a *resistor*
- Ubiquitous device; power amplifying circuit (Space Exploration)

Earth's Van Allen Radiation Belts



Power MOSFET: structure

What is a Power MOSFET?

regulates current flow

Key Features:

Substrates & n-channel (Si)
semiconductor

Insulating layer SiO_2

Metal Gate

Hence: Metal Oxide Semiconductor
or **MOS**

Works How?

Applying Voltage: gate & drain

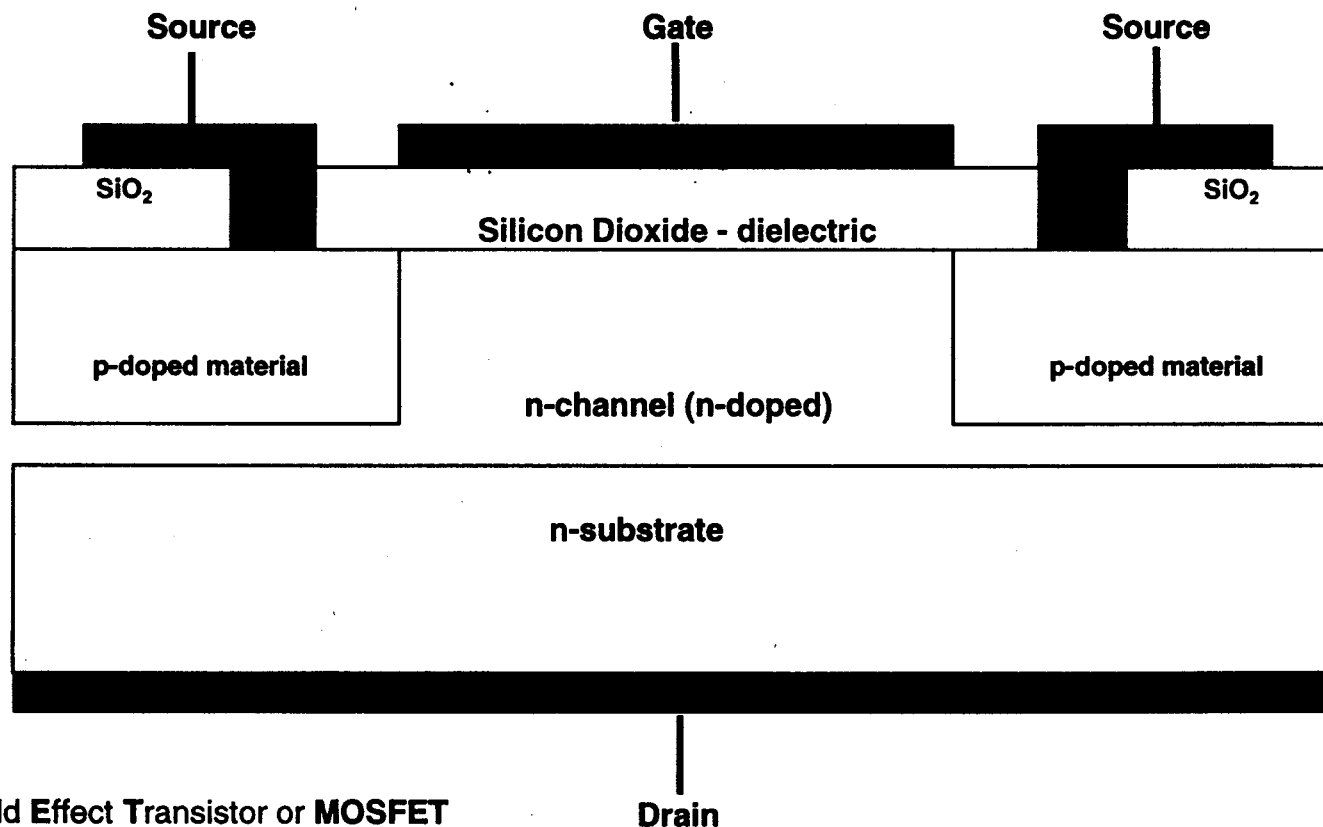
Electric Field

Pulls electrons n-channel

Current flows **S** to **D**

Hence: Field Effect Transistor
or **FET**

Thus, Metal Oxide Semiconductor Field Effect Transistor or **MOSFET**



Power MOSFET: Ion Passage

Description:

E&M predict EHP
Electric Field separates EHP
Electrons to Drain
Holes to Si/SiO₂ (pileup)

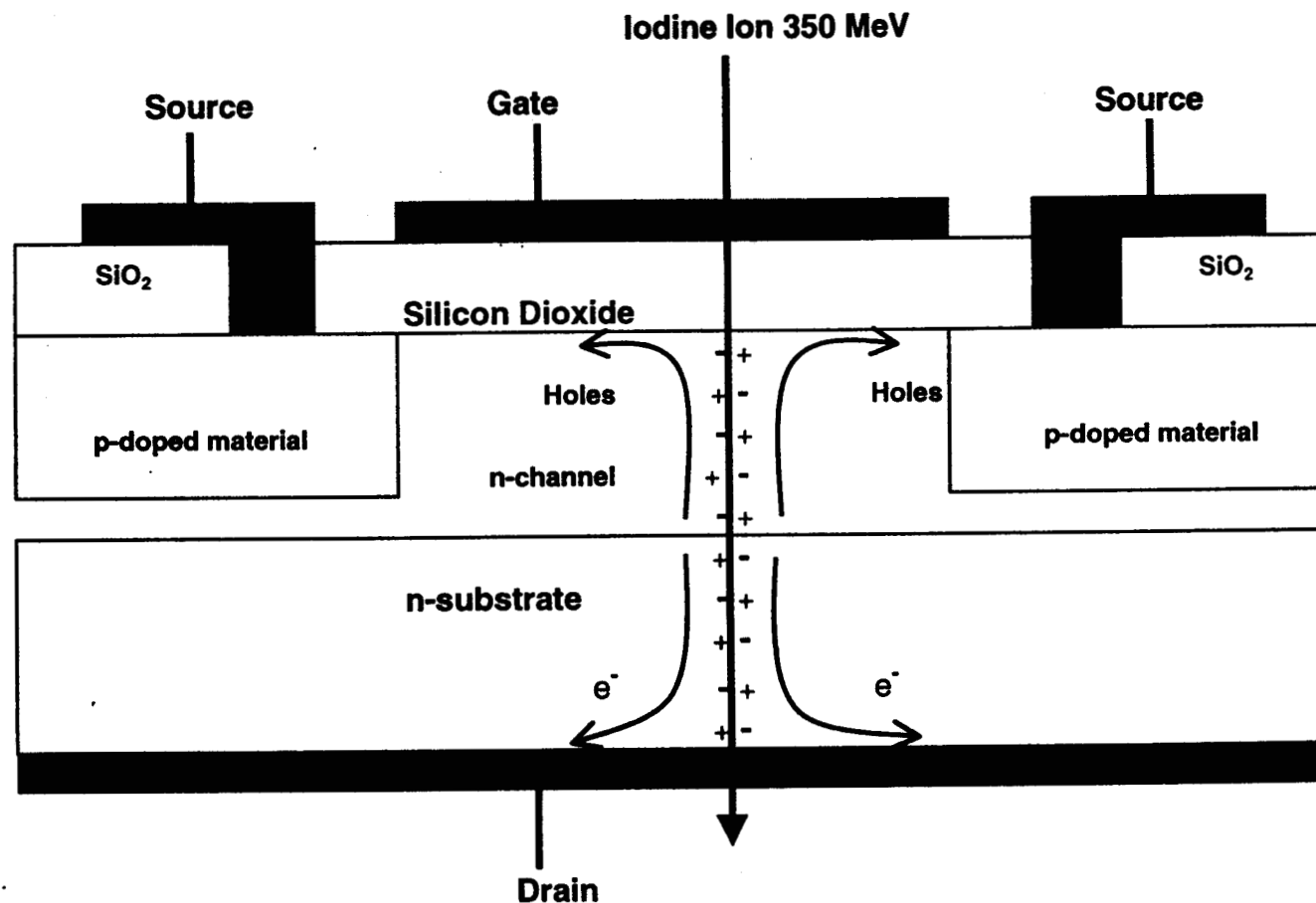
What is a Hole?

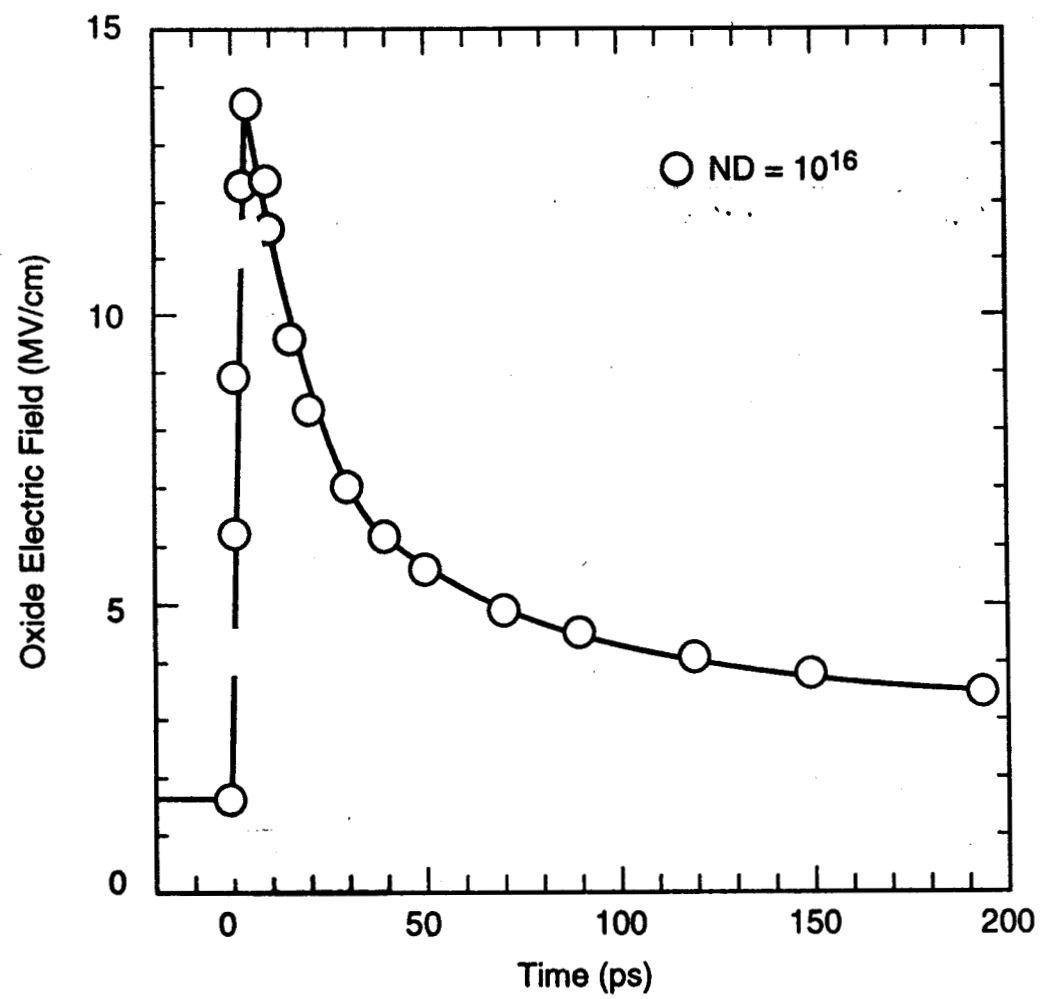
absence of Electron in Neutral atom
S. S. predict Holes & electrons
move opposite due to Electric F.

Effects due to Holes?

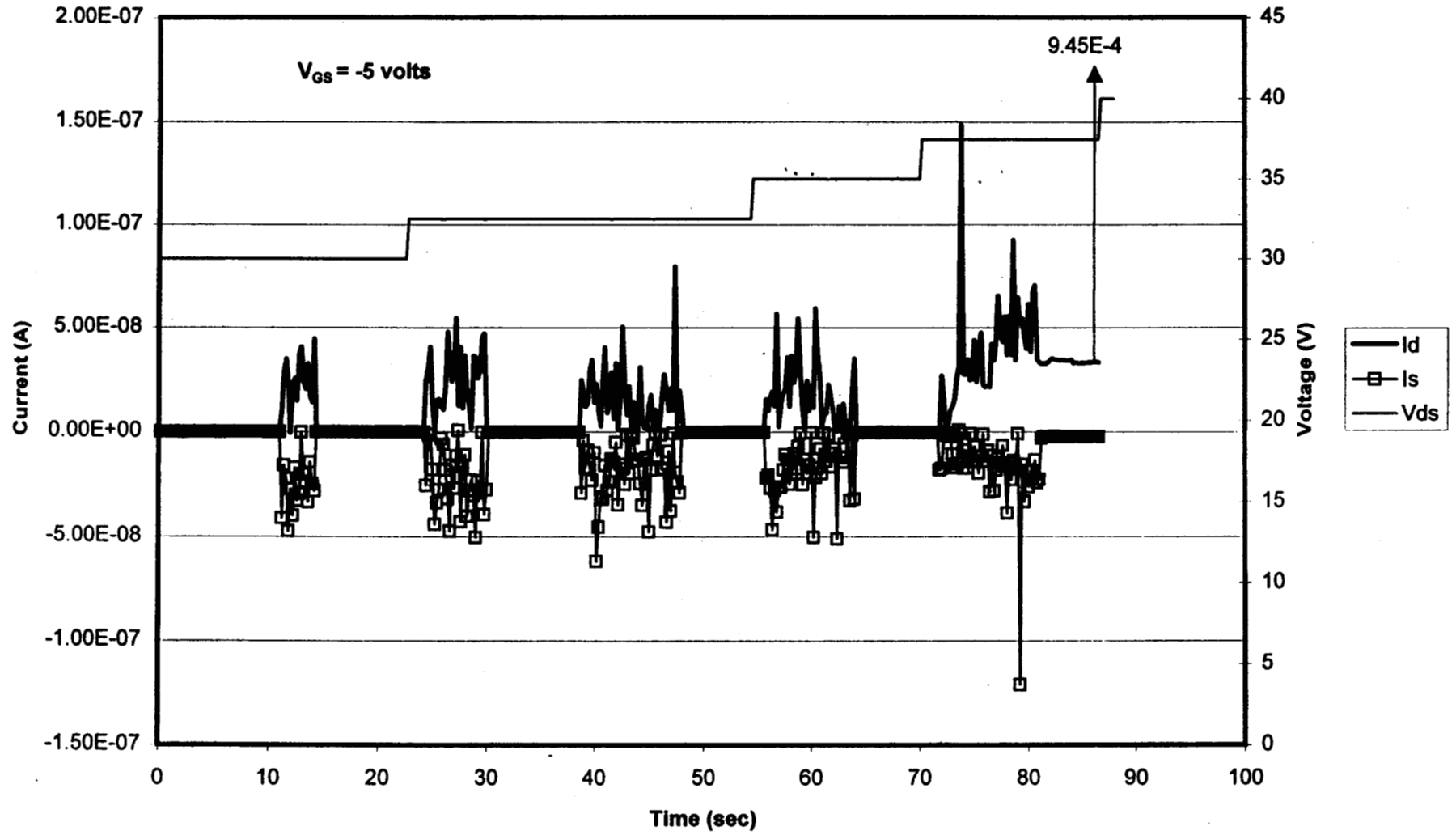
New Intense Electric Field at Oxide
Hence: Ion Induced Electric
Field Transient

Computer Model: PISCES

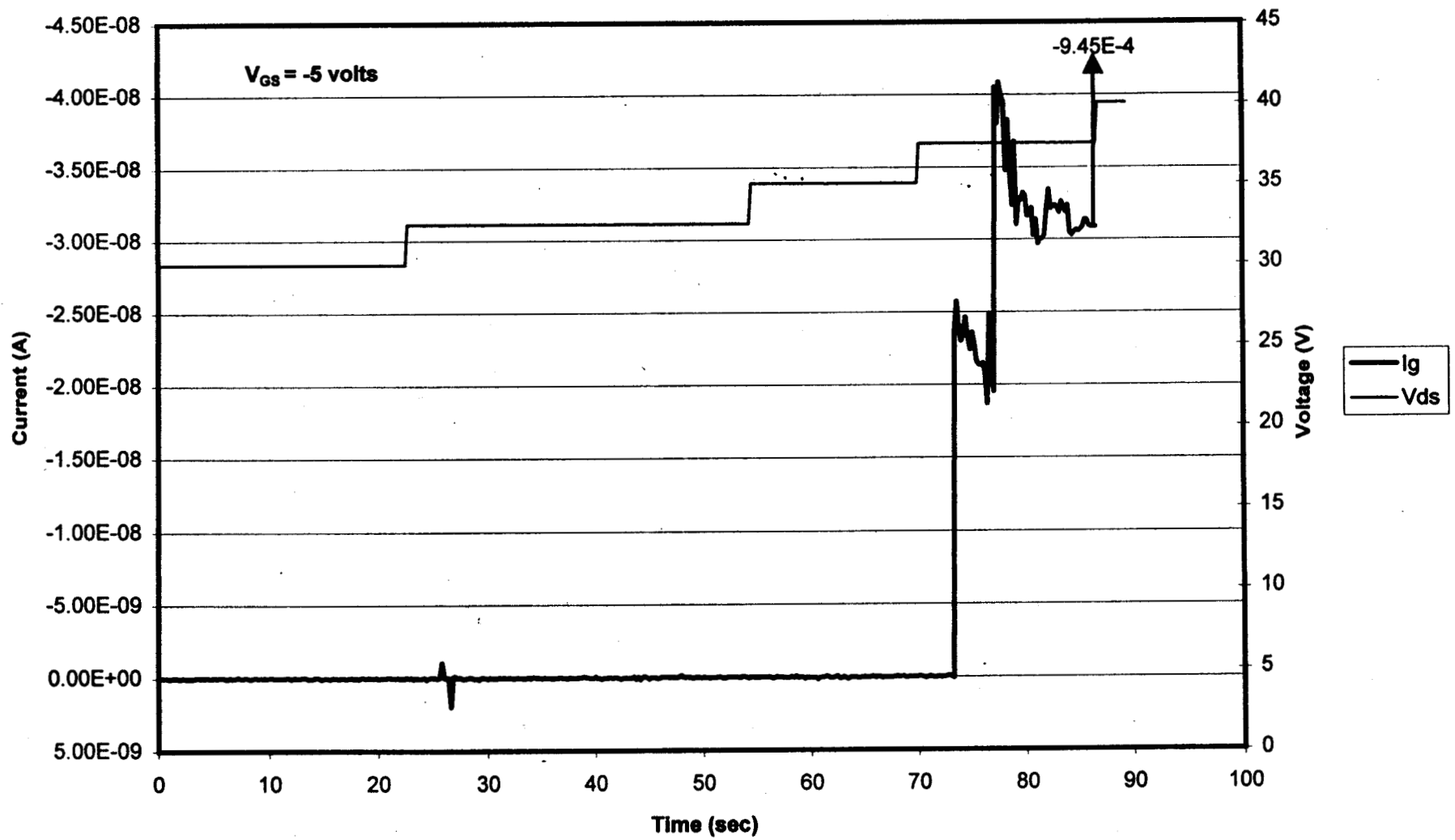




Source and Drain Current vs. Time
FRL130D1 - x2660



Gate current vs. Time
FRL130D1 - x2660





Conclusions

1. Ion Induced Electric Field Transients trigger SEGR.
2. Computer Model show that intense Electric Field Transient is produced following the passage of an Ion.
3. Radiation experiment confirmed that the applied electric field increased the chances of triggering SEGR.

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